EXPOSURE AGE OF SUTTER'S MILL CARBONACEOUS CHONDRITE. K. Nishiizumi[1], M. W. Caffee[2], Y. Hamajima[3], and K. C. Welten[1], [1]Space Sciences Laboratory, Univ. of California, Berkeley, CA 94720-7450, USA (kuni@ssl.berkeley.edu), [2]Dept. of Physics, Purdue Univ., West Lafayette, IN 47907, USA, [3]LLRL, Kanazawa Univ., Nomi, Ishikawa 923-1224, Japan.

Introduction: The Sutter's Mill (SM) carbonaceous chondrite fell in California on April 22, 2012. More than 77 fragments have been recovered with a total mass of over 1,700 g [1]. We have measured the cosmogenic nuclide concentrations to determine the pre-atmospheric size and exposure are of this fall. The cosmic ray exposure (CRE) age is the time interval between a meteoroid's (<several m diameter) ejection from its parent body and its collision with Earth. The distribution of meteorite CRE ages constrains the collisional and orbital dynamics of these objects. The CRE ages of most ordinary chondrites range from several Myr to tens of Myr [e.g., 2]. Based on our measurements of radionuclides in over 130 CM2 meteorites (excluding pairs) we can definitively conclude that these carbonaceous chondrites have CRE age distributions that differ from all other classes of meteorites [e.g., 3]. Our findings [3] are: (1) about one-third of the CM2s have CRE ages less than 1 Myr; (2) nearly one-half of the CM2s have CRE ages less than 2 Myr; and (3) no CM2 chondrites have CRE ages longer than 7 Myr. For those CM2s that have exposure ages <1 Myr, there are two discernable clusters; ~20% of the CM2 and >80% of CM1 are in a cluster corresponding to ages of 0.15-0.25 Myr and ~15% are in a cluster with ages of 0.5-0.7 Myr. These clusters most likely represent collisional events on the parent body. Cosmogenic nuclide abundances in meteorites are also sensitive to the meteoroid size and the depth of the sample within the meteoroid. In this work we measured cosmogenic radionuclides in three fragments of Sutter's Mill to investigate the CRE age, preatmospheric size, and relationship with other CM chondrites.

Samples and Experimental Procedures: Three fragments of Sutter's Mill (SM18, SM43, and SM51) were kindly provided by the owners for this study. A 5.06 g fragment of SM18 and a 3.15 g fragment of SM43 were used for non-destructive γ-ray measurement at the Low Level Radioactivity Laboratory, Kanazawa University, Japan [4]. We used one large well-type Ge detector for non-destructive γ-ray counting, shielded by low-background Pb and Hg, located in the Ogoya underground laboratory. Each sample was inserted in the bottom of the 21 mm diameter well. These particular samples are nearly a factor of 10 less in mass than previously measured meteoritic samples. Some preliminary γ-ray counting results were presented earlier [5]. A small portion of each fragment and a chip of SM51 were used for destructive analysis. Each sample (~50 mg) was dissolved in an HF/HNO_3 mixture in the presence of the Be and Cl carrier solutions. After taking aliquots for chemical analyses by ICP-OES, Be, Al, and Cl were chemically separated and purified for accelerator mass spectrometry (AMS) measurements. The ^{10}Be, ^{26}Al, and ^{36}Cl AMS measurements were performed at PRIME Lab, Purdue University.

Results and Discussion: The chemical composition of each fragment is shown in Table 1. The table also shows average values of our chemical analysis from 126 CM2 chondrites. The major elemental composition is within the range of average chemical composition of CM2 chondrites. The γ-ray counting of SM43 started 29 days after the fall. The counting time was 43,406 min (30 days). The counting of SM18 started 60 days after the fall and lasted 40,622 min (28 days). The counting efficiencies of γ-ray photo peaks were calibrated by several γ-ray standard sources including, ^{22}Na, ^{60}Co, and ^{26}Al. Results of 8 short-lived nuclides are shown in Table 2. Each activity, in dpm/kg, was decay corrected to the time of fall. The presented errors (±1σ) include counting statistics and uncertainty of counting efficiency. The table also shows γ-ray analysis of SM36 (22.3 g) that was measured at the Laboratori Nazionali del Gran Sasso, Italy [1]. The K concentrations of 494±51 (SM18), 453±48 (SM43), and 594±62 (SM36 [1]) ppm are based on ^{40}K γ-ray measurements. AMS measurements of ^{10}Be and ^{26}Al in SM18, 43, and 51 are shown in Table 2. Measurements of ^{36}Cl are in progress. In the table, a ^{26}Al activity of SM36 was measured by γ-ray counting [1].

^{60}Co is produced from thermal neutron-capture on ^{59}Co and is one of the best indicators for determination of pre-atmospheric size and depth. Based on the ^{60}Co activities in SM36 and model calculations [6], the preatmospheric radius is >110 g/cm^2 or ~50 cm based on bulk density of 2.3 g/cm^3. Since the H concentration in SM is not available we use model calculations for L chondrite and 600 ppm of Co (Fig. 1). According to the model, the ^{60}Co depth profiles in both C3+H_2O and L chondrites are similar at depths shallower than 100 g/cm^2 [6]. For a radius greater than ~50 cm, the preatmospheric depth of SM18 must have been <2 cm, SM43 at 4-17 cm, and SM36 at 9-43 cm in the meteoroid.

Assuming these shielding conditions, the ^{10}Be CRE ages are 0.080±0.010 Myr for SM18 and 0.081±0.013

Myr for SM43 and the ^{26}Al exposure ages are 0.085±0.015 Myr for SM43 and 0.095±0.037 Myr for SM36. The average CRE age is 0.082±0.008 Myr, one of the shortest exposure ages among CM chondrites and similar to the CRE ages of ALH 77306 and Asuka 881594 CM2 chondrites. The CRE age obtained by this work is longer than the ^{21}Ne exposure age of 0.051±0.006 Myr [1].

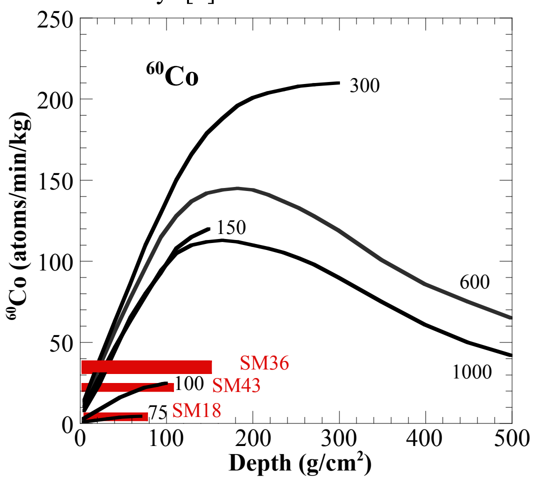

Fig. 1. ^{60}Co production rates as a function of depth [6] and observed ^{60}Co in three SM fragments.

Based on ^{60}Co, SM18 must have been located near the surface of the meteoroid. The cosmogenic nuclide production rates by galactic cosmic rays (GCR) in exterior samples are lower than the production rates of interior samples due to lower secondary particle fluxes. However, the concentrations of many nuclides, especially ^{51}Cr (half-life=28 day) and ^{56}Co (77 day), in SM18 are significantly higher than interior samples (SM43 and 36). Since the last perihelion passage of SM (at a distance of 0.456 AU) was on March 9, 2012, (less than 45 days before the fall of SM), some short-lived nuclides may have contributions from solar cosmic rays (SCR) reactions in the near surface samples. We conclude that the $^{54}Fe(p,\alpha)^{51}Cr$ and $^{56}Fe(p,n)^{56}Co$ reactions by SCR produced those nuclides in SM18 during SM's last passage near the Sun. Although ^{26}Al is also produced by SCR the concentration in SM18 is not high because SM spent most of its orbital period far from the Sun.

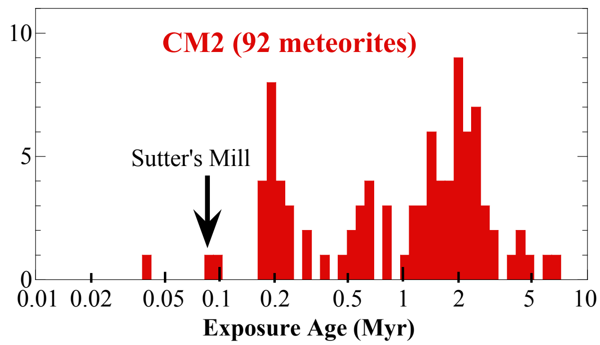

Fig 2. Distribution of CRE age of 92 CM2 chondrites (unpublished) and CRE age of SM.

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References: [1] Jenniskens P. et al. (2012) *Science 338,* 1583-1587. [2] Marti K. and Graf T. (1992) *Annu. Rev. Earth Planet. Sci. 20,* 221-243. [3] Nishiizumi K. and Caffee M. W. (2012) *LPS. 43,* #2758. [4] Komura K. and Hamajima Y. (2004) *Appl. Radiat. Isot. 61,* 185-189. [5] Hamajima Y. et al. (2012) *75th Annual Meteoritical Society Meeting,* #5354. [6] Spergel M. S. et al. (1986) *16th PLSC 91,* D483-D494.

Table 1. Chemical compositions (wt %) of Sutter's Mill and 126 CM2 carbonaceous chondrites.

	Mg	Al	Ca	Mn	Fe	Co	Ni
SM18	12.6	1.24	1.29	0.178	23.1	0.064	1.34
SM43	11.6	1.17	1.24	0.168	21.4	0.057	1.21
SM51	12.2	1.18	1.43	0.179	21.7	0.059	1.24
126 CM2	11.8	1.10	1.16	0.163	20.6	0.060	1.20
(Mean)	±1.1	±0.12	±0.34	±0.013	±1.4	±0.006	±0.12

Table 2. Cosmogenic radionuclide concentrations (dpm/kg) of Sutter's Mill carbonaceous chondrite.

Name	^{10}Be	^{26}Al	^{7}Be	^{22}Na	^{51}Cr	^{54}Mn	^{56}Co	^{57}Co	^{58}Co	^{60}Co
	(1.36×10^6)	(7.05×10^5)	(0.146)	(2.60)	(0.076)	(0.854)	(0.211)	(0.744)	(0.211)	(5.27)
SM18	0.74±0.02	3.50±0.22	201±17	89±7	103±20	144± 8	26±3	16±1	15±2	5.8±0.9
SM43	0.80±0.02	3.36±0.19	212±17	76±7	73±13	117± 6	12±3	11±1	15±2	22±2
SM51	0.83±0.02	3.93±0.21	-	-	-	-	-		-	-
SM36#	-	3.8±0.8*	243±29	122±11	82±24	189±19	11±2	22±2	24±3	34±3

From [1], *γ-ray measurement. Half-life (yr) is shown in parenthesis under each nuclide.